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Evaluation of the incidence of severe trimming on grapevine (*Vitis vinifera* L.) water consumption

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ABSTRACT

Viticulture in Southern Europe heads towards a scenario of drier and warmer the growing seasons due to climate change. This decrease in the amount of water available for the vines and increase in evapotranspiration make necessary finding strategies to reduce vineyard water needs. In this context, the effect of severe trimming (40–60% of shoot length), performed at pea-size stage, on plant water status was evaluated in four different vineyards located in North of Spain. Severe trimming improved plant water status clearly only when climate conditions were more demanding, whereas only a slight improvement or no change was observed elsewhere. Lower leaf areas resulted in less water deficit following a logarithmical trend revealing that the effect was more pronounced at low leaf area levels. Severe trimming had non-significant effects on cluster number, yield and cluster weight, but presents a tendency to reduce total soluble solids content and to increase total acidity, consequently delaying ripening.

1. Introduction

Climate change at a global scale is nowadays undeniable, as it can be deduced from the increase of temperature in the atmosphere and the oceans, the decrease in the surface covered with snow and ice, and the rise of the sea level that have occurred in the last decades. Climate change scenarios not only foresee an increase in temperature, but also changes in the spatial and temporal distribution rainfall (IPCC, 2014) that may increase the occurrence of extreme drought events. Although rainfall patterns are difficult to predict, it is likely that most crops will experience greater water deficit (Lereboullet et al., 2014; van Leeuwen and Darriet, 2016) even in regions where rainfall will not decrease, due to the impact of temperature increase on evapotranspiration (van Leeuwen and Darriet, 2016).

Viticulture in Southern Europe has been recurrently pointed out as especially vulnerable to climate change (Fraga et al., 2016; Jones et al., 2005; Moriondo et al., 2011; Ramos et al., 2008; Resco et al., 2016). Moreover, premium-quality wine areas in Europe might be at risk (Moriondo et al., 2011; Resco et al., 2016) due to increased water needs, decreased yields (van Leeuwen et al., 2017), and to changes in grape composition that may reduce wine quality and typicity (Duchêne et al., 2010; Fraga et al., 2016; Resco et al., 2016; van Leeuwen et al., 2017; van Leeuwen and Darriet, 2016). For instance, the advancement in phenology, consequence of higher temperatures, is already causing earlier harvest dates, and higher sugar concentration and pH in grapes (Neethling et al., 2012; Ramos et al., 2008; Tomasi et al., 2011; van Leeuwen and Darriet, 2016; Webb et al., 2012). Moreover, this advancement also decouples sugar and phenolic maturity processes, leading to unbalanced wines (Bonada et al., 2015; Teixeira et al., 2013).

Sacchelli et al. (2016), in a recent literature review, pointed out that research has been mainly focused to date on the potential effects of climate change in the wine industry, while the interest in developing adaptation strategies from the vineyard has emerged just recently. In this context, there are some studies that propose strategies of adaptation in a short-medium term (changes in oenological practices and in vineyard management, such as modifying training systems and canopy, soil and irrigation management), and in a longer term (variety and rootstock selection or changes in the vineyard location) (Neethling et al., 2017; Ollat et al., 2017; Resco et al., 2016; van Leeuwen et al., 2017). Sacchelli et al. (2016) highlight the compelling need of carrying out studies to evaluate adaptation strategies in different productions areas.

In the last decades, canopy management operations that decrease leaf area to fruit ratio have been widely evaluated, but not as a tool for

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adaptation to climate change, but as a general-purpose cultural practice, determining thus their influence on yield components, berry composition and wine quality (Caccavello et al., 2017; Dardeniz et al., 2008; De Leao et al., 2017; Martínez De Toda et al., 2013; Palliotti et al., 2011; Parker et al., 2016; Poni et al., 2006; Ramos et al., 2008). However, within a climate change context, it is of great interest to determine if decreasing leaf area through shoot trimming or leaf removal reduces grapevine water consumption, as vine water status is widely known to depend on leaf area (Williams and Ayars, 2005). Unfortunately, only a small fraction of the studies analysing the agronomic implications of canopy management practices quantify their impact on vine water status (Pascual et al., 2015; Santesteban et al., 2017; Williams, 2012; Zheng et al., 2017) therefore our study entails a novelty in this area.

Our hypothesis is that severe trimming could decrease transpiration rate and reduce water consumption in grapevine. In this work, we aim at evaluating the effect of severe trimming at pea-size phenological stage on grapevine (*Vitis vinifera* L.) water consumption, yield and grape composition, in order to determine its potential to decrease vineyard water needs in a Mediterranean area.

2. Materials and methods

2.1. Experimental design

The evaluation of the effect of severe trimming on vineyard water consumption was performed using data obtained from four vineyards located in Northern Spain, namely in Navarra (TR), La Rioja (AU-1 and AU-2), and the Basque Country (SA). The cultivars grown were Tempranillo (in TR, AU-1 and AU-2) and Graciano (SA). The main characteristics of each vineyard are summarized in Table 1, and their locations indicated in Fig. 1. The experiment was set-up in years 2014, 2015 and 2016 in the vineyard in Navarra (TR), and in 2017 in those in La Rioja (AU-1 and AU-2) and the Basque Country (SA). Weather conditions for each site and season are summarized in Table 2 and Fig. 3.

In all the vineyards, control vines (CTRL), subjected to standard practices (no trimming), were compared to trimmed vines (TRIM), where a severe trimming had been applied at pea-size stage, removing the upper part of all the shoots (Fig. 2). In TR, treatments were repeated on the same plants in the three seasons considered. The intensity of trimming was set to remove approximately 60% of the upper part of the shoot in AU-1, AU-2 and SA, and 40% in TR. The experimental layout was similar in all the vineyards, being comprised by five replicates per treatment following a fully randomized block design, each replicate including 30–40 adjacent vines. All the measurements and samplings were performed on 10 vines per replicate, which had been selected out of the 30–40 adjacent vines at flowering seeking homogeneity in terms of vegetative growth and cluster number.

2.2. Measured variables

2.2.1. Plant water status

The effect of trimming on plant water status was estimated through the measurement of mid-morning (9:00 h solar time) stem water potential (Ψ_m) between fruit-set and harvest. Determinations were carried out on three healthy leaves per replicate, each one in different vines, which had been bagged 1.5 h prior to measurement using zip-bags covered with a metalized high-density polyethylene reflective film (SonocoRF, Sonoco Products Co., Hartsville, South Carolina, USA). Measurements were carried out with a Scholander pressure chamber (P3000, Soil Moisture Corp., Santa Barbara, CA, USA). Sampling and measurements were performed considering the precautions suggested in Turner and Long (1980).

Additionally, a 50-berry sample at harvest from each replicate was collected, in order to determine the carbon isotope ratio ($\delta^{13}C$) using an Elemental analyzer (NC2500, Carlo Erba Reagents, Rodano, Italy) coupled to an Isotopic Mass Spectrometer (Thermoquest Delta Plus, ThermoFinnigan, Bremen, Germany). Carbon isotope ratio allows for an integration of the water deficit experienced by grapevines along the season into a single value (Santesteban et al., 2015). Carbon isotope ratio was expressed as $\delta^{13}C = [(Rs - Rb)/Rb] \times 1000$, where Rs is the ratio $^{13}C/^{12}C$ of the sample and Rb is the $^{13}C/^{12}C$ of the PDB (Pee Dee Belemnite) standard (0.0112372). $\delta^{13}C$ in TR was determined using whole berry samples, oven-dried and ground to a fine powder, whereas for AU and SA determinations were directly performed in centrifuged must.

2.2.2. Vegetative growth and leaf area

At the end of the season, the effect of trimming on canopy characteristics was quantified by determining the main shoot characteristics (shoot length, number and length of laterals), and estimating vine leaf area through allometric relationships following a three-step procedure (Miranda et al., 2017). First, a sample of 50 leaves gathered from each field was used to establish a relationship between individual leaf area and secondary nerves' length using ImageJ software (Schneider et al., 2012). The relationships obtained were then applied to estimate the leaf area of 20 shoots per replicate (two per vine) by measuring the length of the secondary nerves of all their leaves. Finally, vine leaf area was estimated by multiplying the total number of shoots per vine by the leaf area of a mean shoot.

2.2.3. Yield components and berry composition

The agronomical implications of severe trimming after fruit-set were evaluated by determining yield components and grape composition at harvest, that it was performed at the same date both in trimmed and control vines. Yield was determined by counting and weighing all the clusters produced in the 10 vines in each replicate, whereas grape composition was determined in one 300-berry sample per replicate. The berry samples were formed by 30 berries per vine, picked from 6 different clusters per vine, five taken from each part in the cluster (shoulder, middle, and tip; outside and inside). Samples were carried to

Table 1
Characteristics of the four vineyards included in the study.

	TR	AU-1	AU-2	SA
Location	Traibuenas, Navarra	Ausejo, La Rioja	Ausejo, La Rioja	Samaniego, Basque Country
Cultivar	Tempranillo	Tempranillo	Tempranillo	Graciano
Rootstock	110R	140Ru	140Ru	161-49C
Plant density (vines ha^{-1})	3333	4167	4167	3636
Training system	Bilateral cordon	Unilateral cordon	Unilateral cordon	Bilateral cordon
Drip irrigation	Yes	Yes	Yes	No
Age (1)	17	10	9	12
Altitude	350	467	467	598

(1) Age at the beginning of the experiments in a given vineyard.

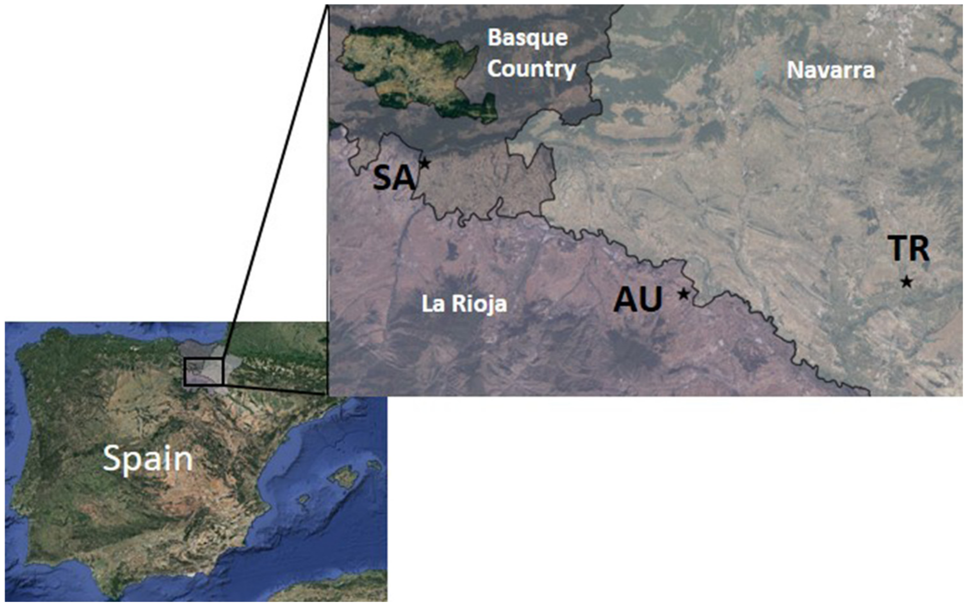

Fig. 1. Location of experimental vineyards within Spain.

Table 2
Mean temperature, rainfall, Heliothermal Index (HI), Cool Night Index (CI) and Dryness Index (DI) calculated for each location (TR: Traibuenas; AU: Ausejo; SA: Samaniego) and season, according to Tonietto and Carbonneau (2004).

	TR			AU	SA
	2014	2015	2016	2017	2017
Mean temperature (Apr-Oct, ºC)	18.5	19.1	18.5	18.5	17.8
Rainfall (Apr-Oct, mm)	312	155.4	153.8	143	182.2
Heliothermal Index, HI	2287	2445	2325	2257	2167
Cool night Index, CI (ºC)	14.5	12.0	14.3	11.8	10.9
Dryness Index, DI (mm)	86	−88	−97	−45	−2

Fig. 2. Examples of trimming and control vines at pea-size stage.

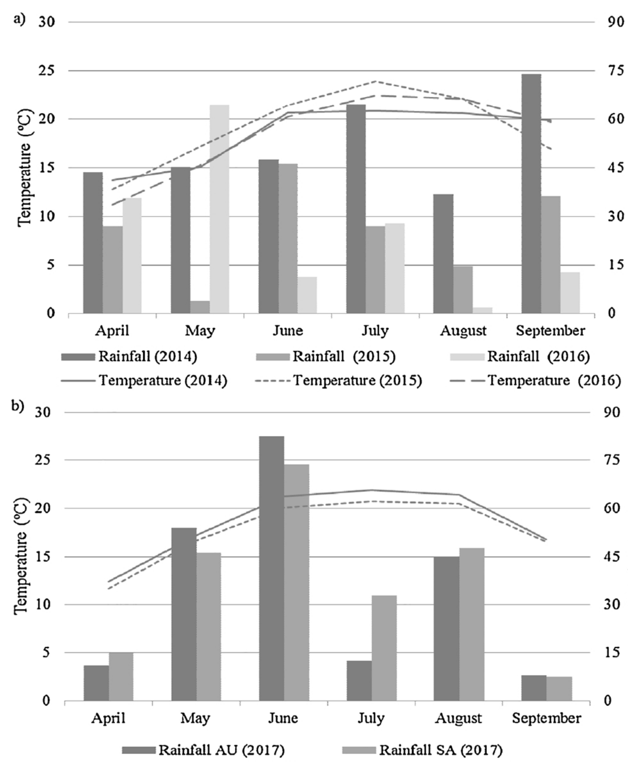

Fig. 3. Climate conditions of the different seasons (April-September) and locations: mean Temperature (Tª) on the month and accumulate Rainfall (mm) on the month in (a) TR-Traibuenas (2014), TR-Traibuenas (2015) and TR-Traibuenas (2016), and (b) in AU-Ausejo (2017) and SA-Samaniego (2017).

the lab at low temperature (4–6 °C) for analysis, weighed to determine mean berry weight (BW), and immediately homogenized with an LMU 9018 American blender (Man, México) for 10 s at full speed. Part of this homogenate (100 g approx.) was filtered with a gauze tissue and used to measure total soluble solids (TSS), pH, titratable acidity (TA) and malic (MalA) and tartaric (TarA) acid concentrations. TSS was measured using a high precision temperature compensating refractometer (RFM840, Bellingham-Stanley Ltd, UK); 20 mL of homogenate were titrated with NaOH 0.25 M up to 8.1 with a pH-Burette 24 (Crison, Barcelona, Spain) to estimate acidity expressed as g TarA L^{-1}. MalA and TarA were determined using an EasyChem multiparametric autoanalyzer (Systea S.p.a., Italy).

2.3. Data analysis

Data were analysed using linear regressions and one-way ANOVA,

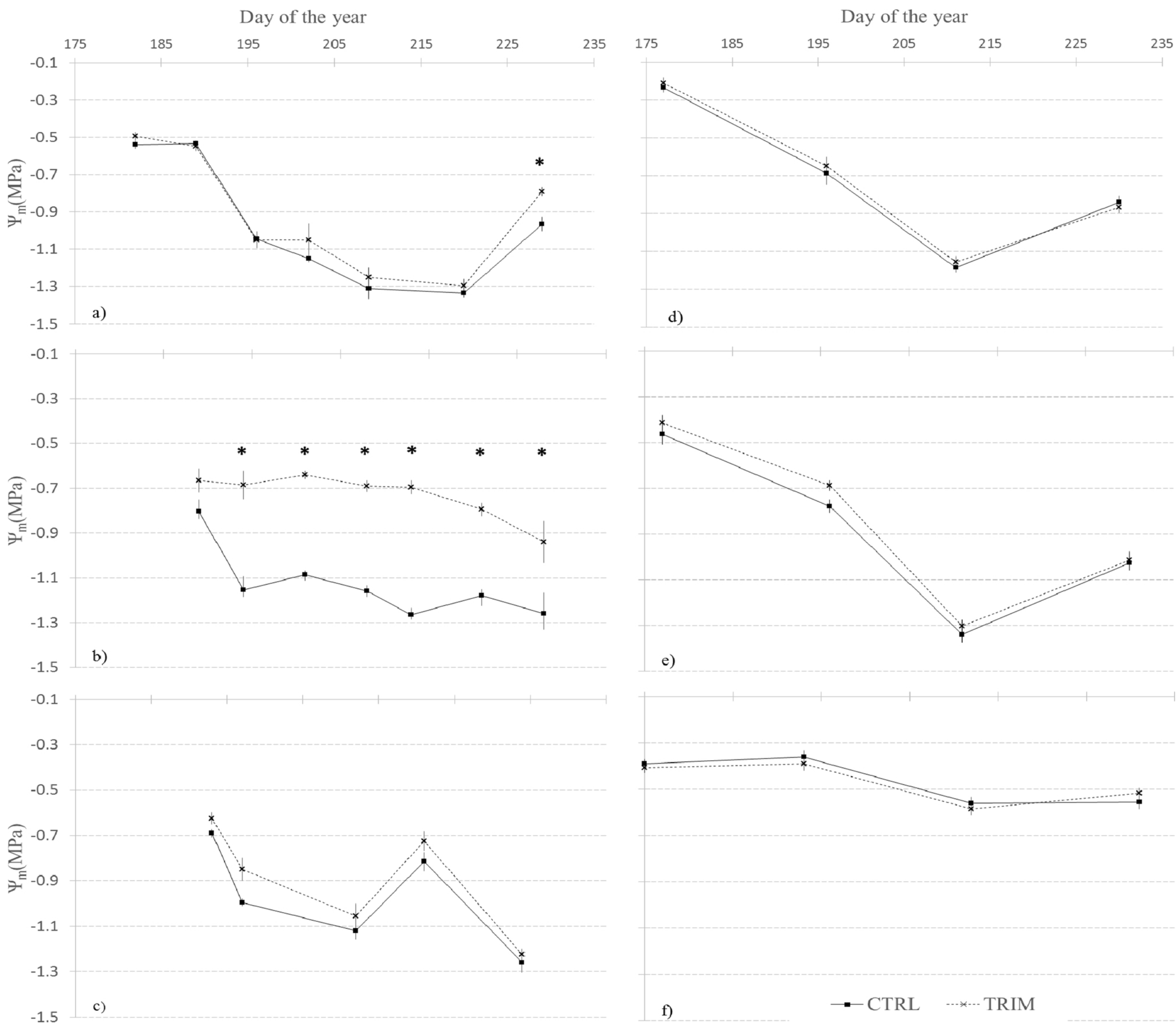

Fig. 4. Effect of severe trimming on the evolution of mid-morning stem water potential (Ψ_m) during the growing season in (a) TR-Traibuenas (2014), (b) TR-Traibuenas (2015), (c) TR-Traibuenas (2017), (d) AU-Ausejo-1 (2017), (e) AU-Ausejo-2 (2017) and (f) SA-Samaniego (2007). *Significant differences, $p < 0.05$.

considering trimming as the main factor, as in a preliminary analysis the interaction between trimming × vineyard/season was frequently significant, making more suitable the individual evaluation of trimming effects at each vineyard. All analyses were performed using R computing environment (R Development Core Team, 2016). The significance level considered was $p < 0.05$.

3. Results

3.1. Plant water status

Severe trimming affected stem water potential differently depending on the season and vineyard considered. There was a general trend of trimmed vines to show higher Ψ_m values for most measurement dates (Fig. 4), though day by day comparison showed those difference to be statistically significant only in TR, throughout the season in 2015, and at the end of the season in 2014. The maximum effect was found in TR in 2015, where the difference between trimmed and control vines was > 0.2 MPa for several weeks. For the remaining sites and seasons, differences between trimmed and control vines were much smaller, and no clear effect was observed either at AU-1 and SA. The results obtained were similar when the effect of trimming on plant water status were measuring through $\delta^{13}C$ analysis, as trimmed vines in TR in 2015 showed much lower values than control plants (Fig. 5), whereas no significant effects were found for the remaining vineyards and seasons.

3.2. Vegetative growth and leaf area

Shoot length in trimmed vines was reduced, as expected, about 35% in TR, and about 55% in AU-1, AU-2 and SA (Table 3). The number of lateral shoots showed no differences between treatments in TR and SA, where the vigour was lower, and it decreased in AU-1 and AU-2. However, total lateral growth length was enhanced by trimming in AU-1 and AU-2, since considering all the laterals altogether, their length increased between approximately 50 and 100%. This effect was not observed in TR, where vineyard vigour was much lower, or in SA, where vigour was relatively low. Leaf area per vine at the end of the season decreased as a consequence of trimming in all vineyards except for AU-1 and AU-2. In fact, in the latter vineyard, the enhanced growth of laterals nearly compensated leaf area loss caused by trimming. For the remaining vineyards, the relative decrease of leaf area associated to trimming ranged between 20–30 % (Table 3).

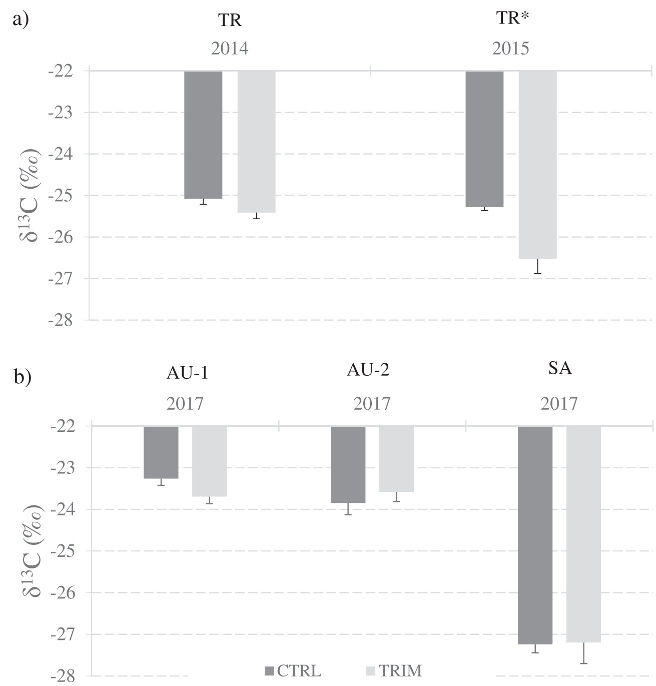

Fig. 5. Effect of severe trimming on carbon isotope ratio ($\delta^{13}C$). (a) TR samples were measured in oven-dried berries, (b) AU and SA samples measured in centrifuged must. No data were available for TR in 2016.
*Significant differences ($p < 0.05$)

3.3. Yield components and berry composition

Severe trimming at pea-size had a very limited effect on yield and its components. No significant differences between treatments were found either for cluster number, yield, and cluster weight at any of the vineyards and seasons considered (Table 4). Berry weight only showed significant differences between treatments in TR in 2016.

Finally, trimming also showed a moderately relevant effect on grape composition. TSS tended to be greater in the grapes from control vines, differences being significant in 2014 at TR, and nearly at AU-2. Total acidity (TA) presented a tendency to higher values in the trimmed vines, this increase being explained by a generally higher malic acid (MalA) content, whereas tartaric acid (TarA) showed no variation (Table 5).

Table 4
Effect of severe trimming on yield components for each location (TR: Traibuenas; AU: Ausejo; SA: Samaniego) and season. P-values < 0.05 have been highlighted in bold.

Vineyard	Year	Treatment	Cluster no.	Yield (kg vine^{-1})	Cluster weight (g)	Berry weight (g)
TR	2014	CTRL	12.00	2.44	204.5	2.03
		TRIM	10.65	2.00	181.0	2.15
		P	0.271	0.188	0.123	0.230
TR	2015	CTRL	6.07	1.51	247.4	1.74
		TRIM	5.52	1.36	250.5	1.82
		P	0.460	0.462	0.863	0.111
TR	2016	CTRL	13.46	2.17	162.2	1.55
		TRIM	12.35	2.06	166.8	1.83
		P	0.141	0.486	0.702	**0.002**
AU-1	2017	CTRL	7.96	1.79	229.2	1.93
		TRIM	7.26	2.08	296.7	1.82
		P	0.539	0.257	0.100	0.395
AU-2	2017	CTRL	8.36	2.67	323.4	2.06
		TRIM	8.40	2.97	353.8	2.25
		P	0.961	0.333	0.336	0.177
SA	2017	CTRL	10.6	2.34	247.9	1.90
		TRIM	10.9	2.46	238.1	1.89
		P	0.688	0.688	0.857	0.909

4. Discussion

In our study conditions, severe trimming did not cause an improvement in plant water status as a general rule, but only when climate was more demanding. This effect was observed in TR in 2015, where trimmed plants showed higher Ψ_m and lower $\delta^{13}C$, indicating certain water saving associated to trimming. This coincides with the results proposed by Herrera et al. (2015), who observed that trimming 50% of the shoot at the end of veraison did not cause relevant differences in terms of water availability under less demanding conditions. Similarly, in those research works where the effects of leaf removal are analysed, it is also frequent to observe no differences in plant water status between treatments (Bindi et al., 2005; Williams, 2012). However, some authors also report a reduction of leaf area through shoot trimming may decrease plant water needs under Mediterranean conditions in cv. Tempranillo (Pascual et al., 2015), preserving water on the first stages of berry growth, that become available on the ripening period. Similarly, Mirás-Avalos et al. (2017) concluded that, under warm and dry conditions, cv. Tempranillo vines with taller (130 cm) canopy, suffered from greater water stress than those that had lower

Table 3
Effect of severe trimming on the length of main shoots and laterals, and on shoot and vine leaf area for each location (TR: Traibuenas; AU: Ausejo; SA: Samaniego) and season. No data were available for TR in 2014. P-values < 0.05 have been highlighted in bold.

Vineyard	Year	Treatment	Main shoot length (cm)	No. laterals main shoot $^{-1}$	Sum lateral length (cm shoot^{-1})	Leaf area (m^2 shoot^{-1})	Total leaf area (m^2 vine^{-1})
TR	2015	CTRL	89.8	1.50	14.8	0.235	2.53
		TRIM	56.9	1.44	19.4	0.186	1.95
		P	< **0.001**	0.770	0.355	< **0.001**	**0.004**
TR	2016	CTRL	79.9	1.33	5.4	0.193	2.18
		TRIM	51.8	1.82	6.6	0.166	1.74
		P	< **0.001**	0.225	0.499	0.073	**0.022**
AU-1	2017	CTRL	146.4	8.62	104.6	0.599	6.08
		TRIM	66.3	5.42	157.1	0.490	5.03
		P	**0.006**	**0.010**	0.132	0.107	0.153
AU-2	2017	CTRL	126.1	8.28	94.1	0.535	5.09
		TRIM	54.3	5.34	196.9	0.504	4.86
		P	< **0.001**	**0.022**	**0.009**	0.707	0.764
SA	2017	CTRL	95.4	8.41	136.6	0.559	7.78
		TRIM	46.8	5.42	109.9	0.400	5.11
		P	< **0.001**	0.073	0.403	0.101	**0.044**

Table 5
Effect of severe trimming on berry composition: total solid soluble (TSS), total acid (TA), pH, tartaric acid (TarA), malic acid (MalA) for each location (TR: Traibuenas; AU: Ausejo; SA: Samaniego) and season. P-values < 0.05 have been highlighted in bold.

Vineyard	Year	Treatment	TSS (ºBrix)	TA (g TarA L^{-1})	pH	TarA (g L^{-1})	MalA (g L^{-1})
TR	2014	CTRL	14.0	3.24	3.62	5.51	1.46
		TRIM	13.7	3.62	3.61	5.97	1.80
		P	**0.019**	0.108	0.715	0.239	0.085
TR	2015	CTRL	14.7	2.59	3.59	6.48	1.59
		TRIM	14.4	2.85	3.60	6.42	1.93
		P	0.291	0.137	0.494	0.321	**0.006**
TR	2016	CTRL	13.5	3.40	3.59	5.90	1.37
		TRIM	13.5	3.67	3.53	5.80	1.57
		P	0.825	0.100	**0.002**	0.434	**0.039**
AU-1	2017	CTRL	15.4	3.23	3.56	7.04	1.42
		TRIM	14.8	3.48	3.55	7.06	1.70
		P	0.146	0.240	0.851	0.894	0.060
AU-2	2017	CTRL	14.5	3.43	3.56	6.98	1.74
		TRIM	13.9	3.86	3.52	6.92	2.02
		P	0.056	**0.004**	0.123	0.453	**0.034**
SA	2017	CTRL	11.9	7.77	3.18	8.40	3.56
		TRIM	11.6	7.75	3.17	8.34	3.46
		P	0.55	0.968	0.764	0.717	0.635

(90 cm).

In order to evaluate the linkage between leaf area and water status, Fig. 6 displays the relationship of the final leaf area of each replicate with $\delta^{13}C$ and minimum Ψ_m, respectively. It can be observed that, for cv. 'Tempranillo', there is a clear significant relationship between leaf area and water status estimated either through $\delta^{13}C$ (Fig. 6a) or Ψ_m (Fig. 6b), following a logarithmic pattern that indicates that above certain leaf area threshold differences in water status become smaller. In the case of 'Graciano', this trend was not clear, as the number of replicates was smaller and water status in SA was much less deficitary (Fig. 6c–d), which agrees with the already mentioned finding by Herrera et al. (2015), who observed that trimming did not cause relevant differences in terms of water availability under low deficit.

The little effect of trimming on water consumption generally observed in our study conditions can be probably due to different mechanisms that compensated water use. On the one hand, lateral shoots develop to compensate the reduction of total leaf area caused by trimming. In our study, even though trimming at pea size stage meant a reduction about 40–60% of shoot length, its effect was not the same at the end of the season, since the reduction of total leaf area was only between 15–30% in most of the vineyards and seasons considered. When the growth of lateral shoots was compared, it could be observed that the two vineyards in AU (i.e., AU-1 and AU-2) reacted to trimming through enhanced lateral growth, even compensating total leaf area loss caused by trimming for AU-2, whereas this behaviour was not observed either in TR or in SA. In TR, low water availability nearly prevented the growth of laterals at all, as it is known to be very sensitive to water deficit (Ojeda, 2007), whereas in SA, where water availability was the highest, the lack of an enhanced leaf area edification through laterals can be assumed to be mainly a cultivar-specific response. Thus, cultivar 'Graciano' has been shown not to be as prone as other varieties to develop laterals (e.g.: Tardaguila et al., 2010, where 'Graciano' was compared to 'Carignan' and shown to emit less laterals). Furthermore,

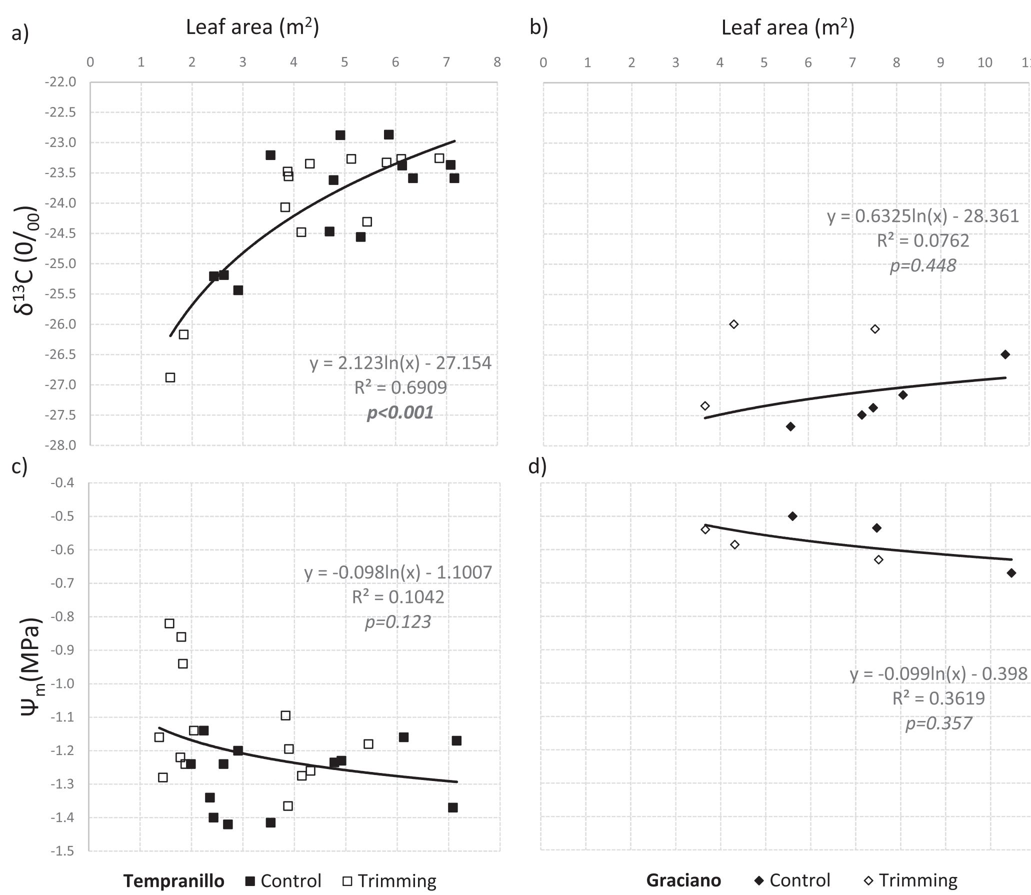

Fig. 6. Relationship of the final leaf area of each replicate with their $\delta^{13}C$ and minimum Ψm values. (a) Cv. Tempranillo $\delta^{13}C$, (b) Cv. Tempranillo minimum Ψm, (c) Cv. Graciano $\delta^{13}C$, (d) Cv. Graciano minimum Ψm.

even though cv. 'Graciano' is a vigorous cultivar, the fact of being grafted on a medium-vigour rootstock as 161-49C could have an effect on limiting lateral growth (Reynier, 2013). Poni et al. (2006), in a relatively humid area in Northern Italy, observed that lateral growth could compensate the prebloom removal of 30% of total leaf area as a consequence of stronger lateral formation. Mirás-Avalos et al. (2017) reported how the trimmed vines in Tempranillo presented more leaf area on lateral shoots, but less leaf area per vine than the not trimmed vines. Furthermore, grapevine has been shown to display additional compensatory mechanisms, as the remaining leaves may become bigger when shoots are trimmed (Fournioux, 1996).

On the other hand, the remaining leaves can compensate the decrease leaf area by increasing gas exchange rates. Poni et al. (2006) reported higher carbon assimilation rates for both main and lateral leaves after veraison in the defoliated shoots, which at the end of the season compensated the detrimental effect of leaf removal on shoot carbon balance. A similar increase in leaf gas exchange variables has also been reported in Candolfi-Vasconcelos and Koblet (1991); Palliotti et al. (2011), and Risco et al. (2014). Additionally, some authors have pointed out that an increased leaf efficiency could be reached in the remaining leaves of partially defoliated vines as a consequence of an increase in the intrinsic water use efficiency (WUE_i) and in tolerance to photoinhibition (Palliotti et al., 2011), or due to an increase of the chlorophyll content and to a delay of leaf senescence (Candolfi-Vasconcelos and Koblet, 1991).

Another factor that may have affected the relatively limited effect of severe trimming on vineyard water status is linked to vineyard characteristics. Crop load was moderate in all vineyards, as regulatory limitations of yield apply in regions where the experiments took place (legal limits are 8000 kg ha^{-1} in D.O. Navarra and 6500 kg ha^{-1} in D.O.C. Rioja). Higher crop loads result in an up-regulation of leaf photosynthetic activity and transpiration (Naor et al., 1997), which leads to an increase in water consumption (Bravdo et al., 1985; Intrigliolo and Castel, 2011; Santesteban et al., 2011). Therefore, it would be sensible to hypothesise that more relevant effects would have been observed if crop load had been higher. Last, the fact cv. Tempranillo has been used in 5 out of the 6 vineyard-season combinations analysed may also have conditioned the results obtained. This cultivar has been shown to maintain high water consumption even under moderate water stress (Medrano et al., 2003; Santesteban et al., 2009; Vaz et al., 2016), making more likely the occurrence of compensation mechanisms increasing individual leaf gas exchange.

With regards to the agronomic implications, there were no significant effects of the trimming treatments on cluster number, yield and cluster weight at any of the vineyards and seasons considered, as occurs in Dardeniz et al. (2008); De Leao et al. (2017), and Pascual et al. (2015). However, most previous research reports show a decrease in yield as a consequence of reducing leaf area, to a greater or lesser extent. Poni et al. (2006) found that early removing leaf or trimming caused lower yields, due mainly to a decrease in the number of berries. In the first case, leaf removal is made before bloom, and this can condition the fruit set. In the second one, trimming took place after bloom and this could induce a little grape shatter. Previous research has demonstrated that the carbohydrate shortage caused by leaf removal (defoliation or trimming) can affect negatively bunch and flower initiation and differentiation processes and, therefore, can result in a decrease in vine fertility and yield in the subsequent year (Basile et al., 2015; Bennett et al., 2005; Candolfi-Vasconcelos and Koblet, 1990). Nevertheless, Poni et al. (2006) reported no carry-over effects of defoliation on the following year's bud differentiation in a 3-year experiment. Martínez De Toda et al. (2013) also found lower yield associated to severe trimming, although this decline was mainly due to a decrease in berry weight. Our results do not allow a proper analysis of this carry-over effect, as the experiment was repeated only in one of the vineyards (TR). In this case, yield, cluster number and berry weight decreased only in the second season of trimming, which could be partly due to such carry-over effect. Regarding grape composition, in our study trimming generally reduced soluble solids concentration and presented a tendency to increase acidity. TSS decrease agrees to the response observed in cv. Aglianico by Caccavello et al. (2017), in cv. Pinot Noir by Parker et al. (2016), in cv. Merlot by Herrera et al. (2015), and in cv. Tempranillo by Martínez De Toda et al. (2013); Pascual et al. (2015); Santesteban et al. (2017). The reduction of the TSS is claimed to be mainly due to a decrease in total vine light interception that limits carbohydrate production (Caccavello et al., 2017; Martínez De Toda et al., 2013; Parker et al., 2016). However, Mirás-Avalos et al. (2017) indicate that under their study conditions differences in canopy affected vine water status but not photoassimilate supply, those conditions were not as limiting as ours in terms of leaf area maintained. With regards to acidity, just Herrera et al. (2015) reported a similar effect, whereas other authors observed no changes (Martínez De Toda et al., 2013; Parker et al., 2016; Pascual et al., 2015).

5. Conclusion

Severe trimming performed on pea-size stage did not show a great potential as a tool to reduce grapevine water consumption under the study conditions, showing just a moderate effect when the most demanding evaporative conditions occurred. Lower leaf areas resulted in less water deficit following a logarithmical trend that highlighted that the effect was more relevant when low leaf area levels were reached. Therefore, unless very severe water deficit conditions are expected and leaf area remarkably reduced, other alternatives should be explored to reduce vine water use.

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